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MAGNETIC ORDERING IN RE-ENTRANT (PdFe)Mn STUDIED BY AC SUSCEPTIBILITY AND MAGNETORESISTANCE MEASUREMENTS

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Abstract. - The linear and non-linear magnetic response and the low field magnetoresistive anisotropy of re-entrant (PdFe)Mn have been measured near both "candidate" transitions.

The consensus of current experimental data is that while the entire magnetic response of a ferromagnet is singular

$$x_F(h, t) = t^{-\gamma} G \left( h / t^{\gamma+\beta} \right) \sim \frac{1}{t^\gamma} - \frac{h^2}{t^{\gamma+2\beta}} + \ldots \ (1)$$

the singular component in a spin-glass appears in the non-linear response alone:

$$x_{SG}(h, t) = x_0(t) - \frac{h^2}{t^\delta} + \ldots \ (2)$$

(primes are used to distinguish the exponents in spin-glasses from those in ferromagnets); $x_0(t)$ behaves regularly.

Here we summarise the results of the first measurements of the non-linear response of a re-entrant system, (Pd + 0.35 at %) + 5 at % Mn. Samples near this composition have been reported previously to have a ferromagnetic Curie temperature $T_c$ near 10 K and a spin-glass temperature $T_{SG}$ near 4 K [1], although these conclusions were based primarily on measurements of the linear response (the zero field susceptibility).

For the present sample from susceptibility data, we find a well defined ferromagnetic transition at $T_c = 9.30 \pm 0.02$ K characterised by exponent values:

$$\gamma = 1.64 \pm 0.07 ; \ \beta = 0.53(5) \pm 0.08 ;$$

$$\delta = 4.1 \pm 0.1.$$ 

In terms of the non-linear response, in figure 1 we reproduce the temperature dependence of the $h^2$ term, $a_2(T)$, obtained from the field dependence of the ac susceptibility ($\chi_{ac}$). According to equation (1) this should vary as $t^{-3\gamma-2\beta}$ ($t = (T - T_c) / T_c$), with $3\gamma+2\beta = 6.0 \pm 0.4$ (using the above values), compared with a slope of $0.2 \pm 0.6$ from this figure. Deviations from this temperature dependence for $t < 5 \times 10^{-2}$ arise from increasingly important $h^4, h^6$ and higher order terms of alternating sign (even in fields of $\sim 3$ Oe); a similar situation occurs at direct paramagnetic-ferromagnetic [2] and paramagnetic-spin glass transitions [3]. Thus in all these systems the non-linear response is dominated by its leading $h^2$ term only in vanishing small field as the critical temperature is approached.

The coefficient of the $h^2$ term, $a_2(T)$, has also been estimated near the spin-glass temperature $T_{SG}$ from $\chi_{ac}$. While we are aware that finite frequency measurements are constrained by the slow dynamics of spin-glasses close to $T_{SG}$ [4], we nevertheless observe for the first time in a potentially re-entrant system a peak in this coefficient at 4.07 K; figure 2. We expect measurements made at frequencies below the 2400 Hz used here will only serve to accentuate the peak evident in this figure, as observed at the direct paramagnetic-spin glass transition in PdMn [5] (and for this reason we are unable to quote a reliable value for $\gamma'$ below $t = (T - T_{SG}) / T_{SG} \sim 10^{-3}$). We believe that such a peak structure may be an intrinsic feature of a true re-entrant ferromagnetic-spin glass transition since similar measurements carried out below $T_c$ in two PdMn sample (with 4 and 4.5 at % Mn) which exhibit some re-entrant features [6], do not exhibit a peak in $a_2(T)$. Since these latter samples certainly possess domain walls, we conclude that the observed peak is not a consequence of domain wall motion. SQUID measure-
ments at a much lower frequency ($\sim 16$ Hz) are being carried out on these systems at present.

The longitudinal ($\rho_\parallel$) and transverse ($\rho_\perp$) magnetoresistance of the (Pd(Fe))Mn sample has also been investigated at 4.2 and 1.5 K (Fig. 3) for fields below 10 kOe. The data are similar at both temperatures, showing a substantial negative magnetoresistance (the zero field resistivity is about 8.3 $\mu\Omega\text{cm}$) which does not saturate in low field. This makes any estimate of the magnetoresistive anisotropy very difficult to obtain, as in (PdNi)Mn [7]. It is clear however from the 4.2 K data (acquired well below $T_c$ but above $T_{SG}$) that the system does not behave as a uniform ferromagnet below $T_c$ (despite the conclusions drawn from the susceptibility data), and furthermore there is no obvious change in the magnetoresistive properties on passing through $T_{SG}$. These data confirm that the spins in this low temperature state are not fully aligned, in agreement with conclusions drawn, for example, from nuclear orientation studies [8].

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